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Fibre-Reinforced Adhesive for Structure Anchoring

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Abstract. The topic of this paper is the glue-concrete interface of bonded anchors loaded by tension force. The paper is closely focused on bond strength experiments using high strength concrete up to class C50/60 or higher together with pure epoxy resin and fibre-reinforced resin. The goal of this research is to find the limits of the effective use of such glue types in high performance concrete, and also to verify the most commonly used design methods for bonded anchors. The presented research includes experimental analysis of the glue-concrete interface and the influence of its parameters on anchor behaviour. The presented analysis shows some problems of the ‘separated failure modes’ approach and also presents experimentally verified bond strength values obtained for the currently most widespread glue types. Results of fibre reinforced epoxy resin are also presented in this paper.

1. Introduction

The base line of this analysis consequents from one of the typical failure types of bonded anchor loaded by static tension force. According to widely spread ETAG documents [1] and also new EC standard [2], the failure type implied by adhesive compound is in general defined by bond strength value.The characteristic value of anchor resistance corresponding to this failure type is given as (1).

$$N_{Rk,o} = \pi \cdot d \cdot h_{ef} \cdot \tau_{Rk} \tag{1}$$

In equation (1),h_{ef} is the effective anchorage length, τ_{Rk} is the characteristic bond strength, and d is the anchor bolt diameter.

The bond strength is defined as the peak value of tangential stress on the defined contact area in most cases. Contact area is given by effective anchoring length and diameter. In principle, the correct diameter should be used according to the failure position. However, it is very difficult to determine the correct failure mode for specific anchoring conditions. Using the anchor bolt diameter leads to complete neglecting of the thickness of the adhesive layer, figure 1.

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This is an acceptable model of problem simplification because layer thickness for most bonded anchors systems is equal to several millimetres (according to anchor bolt diameter 1 or 2 mm). The bond strength as a material parameter defined in this way does not represent real material characteristic in many cases [3]. If the failure on the steel anchor bolt and adhesive compound occurs, the tangential stress on the contact area is not a bond stress (or bond strength in the peak value) but rather the shear strength of the adhesive itself. It is possible to assume that there is no adhesion failure on concrete-glue contact either.

Figure 1. Bond failure close to glue-concrete contact defined by drill diameter $d_{o.}$

1.1. High-strength concrete effect

The surface of a drilled hole (at least in the usual case of hammer drilling procedure) is very rough/bumpy. Failure on this contact means the failure of concrete or glue, or both materials. The weaker from both materials affects the failure on themajor scale. This simple assumption means that anchor resistance cannot be increased by the use of high strength concrete without the use of high performance adhesive as well.

Problems connected with the combined concrete-bond failure mode are in detail described in [4]. The following relation (2) for the tensile resistance of an anchor experiencing the combined concrete-bond failure mode has been published in [4].

$$N_{Rk} = \pi \cdot \tau_{Rk} \cdot d_o \cdot h_{ef} \cdot 0.74\left(1 - e^{-1.5\frac{f_{cc,150,k}}{\tau_{Rk}}}\right) \tag{2}$$

In equation (2),h_{ef} is the effective anchorage length,$f_{cc,150,k}$is the characteristic compressive concrete strengthassessed for 150 mm cubes,τ_{Rk} is the characteristic bond strength, andd_0 is the diameter of the drilled hole.

Equation (2) was determined from experimental results (pull-out tests and bond quality tests) for the currently most widely used industrial glues based on vinyl-urethane resin, polymer cement mixtures and epoxy resin. All tests were conducted using common concrete ranging in class from C15/20 to C37/45 [5].

Figure 2 shows the results obtained by equation (2) for different bond strength values in relation to concrete strength. According to the previous experimental results for the bonds provided by currently used glues [4], [5], such bond strengths range from 15 to 20 MPa. This bond strength value, together with the standard anchorage length, which is about nine times the anchor diameter, ensures the effective utilization of materials with a concrete class of up to C40/50 and a steel bolt quality of 8.8.

For anchoring in high-performance concrete without using extended anchorage lengths, it is necessary to also use high strength steel such as 10.9 or 12.9 or different materials for the anchor bolts, for example, composite fibres. However, the bond strength provided by the glue remains the limiting parameter for this kind of anchor application.

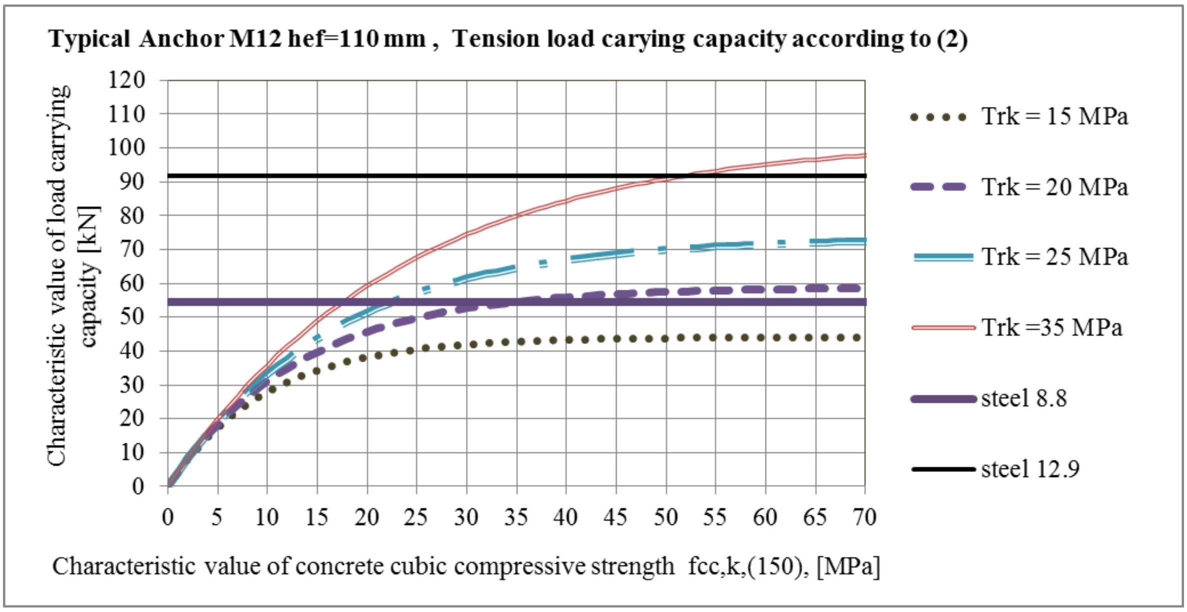

Figure 2. Tension load carrying capacity according to (2).

2. Fibre reinforced epoxy resin

One of the ideas is to reinforce the glue layer by carbon or glass fibres. The size of the contact area (and also the stress value) is influenced by the diameter. When the glue strength is lower in comparison to concrete, failure “a” will be located around the anchor bolt diameter d. By improvement of glue strength the failure moves towards the concrete contact around the drilled opening diameter d_o – failure “b”. Both the area of contact and the bond strength increase, figure 3.

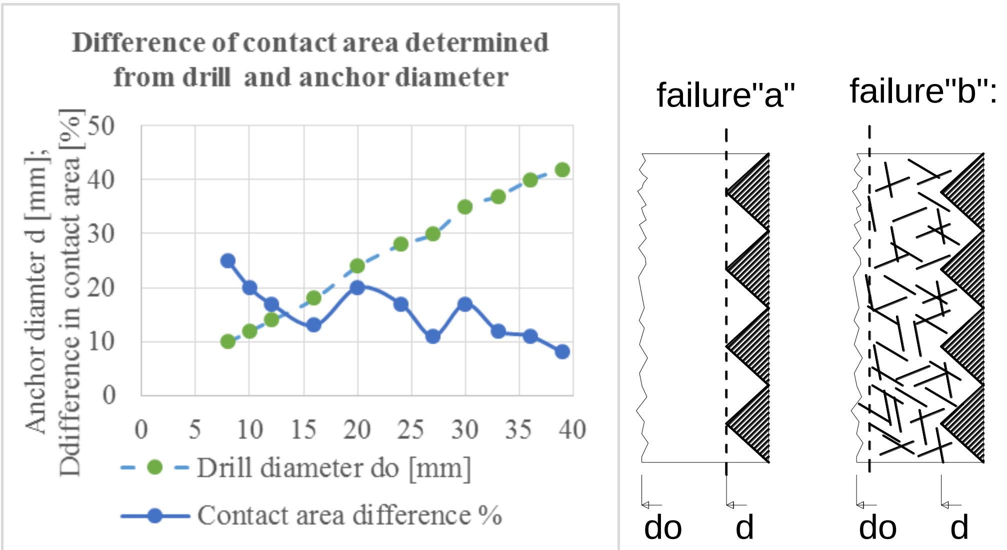

Figure 3. Differences of contact are determined from drill and anchor diameters.

This improvement is limited by the difference between diameters. The theoretical value of percentage improvement for common anchor diameters is summarised in table 1.

Table 1. Typical values of anchor and drill diameters for epoxy resin anchor types.

Anchor diameter d [mm]	**8**	**10**	**12**	**16**	**20**	**24**	**27**	**30**	**33**	**36**	**39**
Drill diameter do [mm]	10	12	14	18	24	28	30	35	37	40	42
Contact area difference %	25	20	17	13	20	17	11	17	12	11	8

2.1. Experiment

The main principle of the bond quality test used (as depicted in figure 4) [1] is to restrict bond failure to the anchor only. Load is applied to the anchor bolt by the loading mechanism, which is itself supported by the concrete in the immediate vicinity of the installed anchor. Experiments are comprehensively described in [4] and [5], where the results for several types of adhesives used in concrete C20/25 are also presented. The main result is the experimental study adverting to values of bond strength of the currently used glues. These are usually in the range between 15-25 MPa. This is also enough for concrete up to C50/60 class.

Glues based on epoxy resin usually give the best values of bond strength. The disadvantage of this type of glues is the long hardening time at normal temperatures (it takes several hours to reach significant values of strength and several days to reach full strength). The glue used in the following experiments was also based on epoxy resin but it was produced with an aim to reach maximum shear strength [5].

Two sets of test were performed. Anchors in the first set of experiments were installed in high strength concrete with mean value of compressive cubic strength 75.8 MPa, which corresponds to class C60/75. The concrete specimens were prepared in the shape of a cube with edge length 200 mm. The predetermined length of the contact was 40 mm. The steel rebar M12 12.9 was used as an anchor bolt. Concrete specimens were substituted by steel specimens in the second set. Another metric thread was performed in the specimen opening to face the anchor bolt surface. This configuration ensures the shear failure of glue itself. Therefore, the shear strength of adhesive can be determined. Specimens with plain epoxy adhesive are marked as N and specimens with fibre reinforced epoxy resin are marked as C.

Figure 4. Experiment configuration.

In all tests the anchor was loaded by constantly rising tension force using hydraulic press with central opening, see figure. 4. The speed of loading was 2 kN per second. The applied force and the vertical deflection of the anchor bolt were also constantly measured. The temperature during the installing of the anchor, hardening time and testing was around 20°C. During specimen preparation, the standard cleaning procedure was used [6]. That means cleaning by air blowing (hand pump) and brushing with steel brush.

2.2. Results

Figure 5 shows both specimens after failure. The difference between failure positions is obvious. Bond failure for specimens with epoxy glue reinforced by carbon fibres occurred on the concrete glue contact or, more precisely, close to the area defined by drill diameter d_o.

Figure 5. Experiment configuration – plain epoxy (left); reinforced epoxy (right).

Figure 6 shows a load deformation diagram from experiments in high strength concrete for three tests of each type of glue.

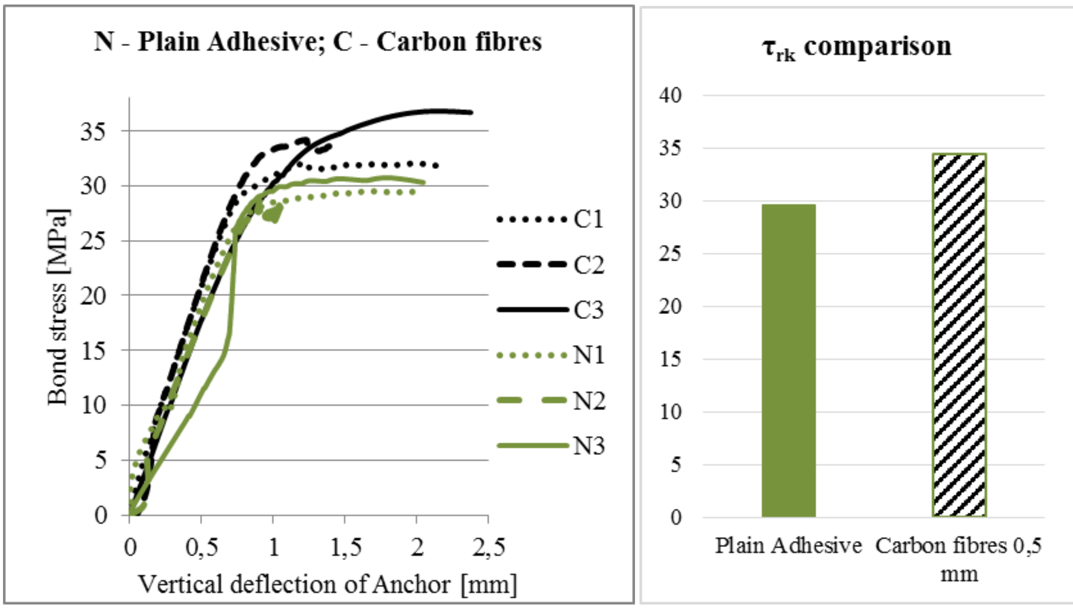

Figure 6. Experimental results; load deformation diagram.

Figure 6 also shows the comparison of mean values of bond strength determined from these experiments.

The difficult part here is to determine the amount of fibres which should be added to the compound. The reinforcement ratio has to be analysed in further research. There is a problem with the viscosity of the final adhesive compound.

Raising the amount of fibres leads to the loss (decrease) of viscosity. As the first approximation, the reinforcement ratio was set to 10% of the weight of the plain epoxy resin. Carbon fibres were melted to size lower than 0.5 mm. Material characteristics of the fibres were Young modulus 230 GPa and

tension strength 3600 MPa. The epoxy adhesive consists of two components which have to be mixed together in specific ratio. Fibres were first mixed with one component (not the activator) by accu-screwdriver by 600 rpm, for one minute. After this the fibres looked well-mixed in the compound.
The procedure of mixing used for the presented starting sets of specimens is not ideal, because it cannot prevent the formation of air spaces.In further experiments, the use of vacuum mixing is planned.

3. Summary and conclusion

Only a small number of tests were performed for such kind of fibre reinforced epoxy resin glue. In spite of that, there is a positive influence of carbon fibre reinforcement. This type of reinforcement enhanced the bond strength by 10% or more. The difference in the tension load carrying capacity for failure on the steel-glue contact and the failure on the glue-concrete contact cannot reach the theoretical value described in table 1 only by the useof fibre reinforcement. This is because fibre reinforcement is not active on the contact area defined by diameter d_0. However, it is obvious that bond connection of adhesive anchors can be improved in this way. Larger amount of small fibres has a greater effect on the adhesive compound shear strength. The correct amount of fibres, their size, and mixing procedure are the issues for further research activities.

This kind of adhesive anchor system (threaded rod + adhesive) can remain the simplest anchoring solution also for high performance concrete with compressive strength over 60 MPa. According to the presented results, reinforcing of currently used industrial adhesives is an effective solution.

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